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Distributed Information-Based Cooperative Strategy Adaptation in Opportunistic Mobile Networks

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Abstract—Cooperation among nodes is a fundamental necessity in opportunistic mobile networks (OMNs), where the messages are transferred using the store-carry-and-forward mechanism, due to sporadic inter-node wireless connectivity. While multiple works have addressed this issue, they are often constrained in their assumptions on solutions (e.g., requirement of central authority, and tracing the recipient nodes for providing reward or punishment). In this work, we address this research lacuna by taking an evolutionary theory-based approach. In evolutionary theory, the players analyze alternative strategies and select the best one to survive in a population. Inspired by this, in this work, we propose a *Distributed Information-Based Cooperation Ushering Scheme (DISCUSS)* to promote cooperation in message forwarding between nodes. In this scheme, the nodes maintain and exchange information with one another during contacts about the messages created and delivered in the network. Based on this, the nodes evaluate their own performance and compare that with the approximated network performance to adapt the most successful forwarding strategy. Simulation results show that the message delivery ratio in the network improves upto 31 percent, when the nodes dynamically switch their strategies, as compared to the case when they do not. Furthermore, the DISCUSS scheme fared closely to its variant with the nodes having complete knowledge about the network-wide performance.

Index Terms—Cooperation, opportunistic mobile networks, strategy adaptation

1 Introduction

Opportunistic mobile networks (OMNs) are a subclass of delay-tolerant networks (DTNs) [1]. In traditional wireless networks, end-to-end communication paths usually exist between the source and destination node pairs, which, however, is not true for the OMNs. The messages in OMNs are "opportunistically" routed to their destinations using the store-carry-and-forward transfer mechanism. Mobility among users creates new opportunities to connect and communicate with one another using wireless devices [2]. Since the source-destination pairs might not be connected simultaneously, route maintenance exhibits a huge challenge. So, the routes are typically computed at each node based on the local knowledge of the node. A source node delivers its message to the destination node, if both the nodes come in contact of each other. Otherwise, the message is forwarded to the intermediate nodes, which then store and carry the messages, until one of them meets with the destination and delivers, or they can find other nodes which can do the same. Thus, message forwarding in OMNs significantly depends on the cooperation of the intermediate nodes.

Existing routing protocols such as [3], [4], [5], [6], [7] make the assumption that the nodes are fully cooperative. Since the nodes are typically unmanaged, it is difficult to coordinate different nodes having different goals. So, we do not always consider fully cooperative behavior among all nodes. Mobility in OMNs causes nodes to meet opportunistically. These opportunistic connections help certain nodes to transfer their messages through intermediate nodes to the corresponding destination nodes. Some nodes may take help from others for forwarding their own messages, but may not always help in forwarding others' messages. This selfish behavior heavily affects the network performance. The mobility and the greedy nature of the nodes require a distributed and efficient cooperation scheme that can stimulate cooperation and discourage non-cooperative behavior.

Enforcing cooperation among nodes has been extensively studied in the literature. One way of promoting cooperation among nodes is to give reward or punishment. However, for giving reward or punishment, the recipient node needs to be traced. Zhu et al. [8] proposed 'iTRUST', in which a periodically available trusted authority (TA) judges each node and detects the misbehaving nodes. Credit-based incentive schemes [9], [10], [11] were proposed, in which credit is given to the forwarding nodes in terms of virtual pricing unit. Wei et al. [12], and Zhang et al. [13] proposed reputation-based incentive schemes for encouraging cooperation among nodes. Wu et al. [14] proposed a game theoretic approach that encourages cooperation among nodes. However, the scheme proposed by these authors is based on the use of a server (credit clearance centre) for updating each transaction. In another scheme, 'Pi' [15], the source node attaches some incentives on the forwarding message.

In this work, we consider three groups of nodes based on three strategies of message forwarding—*cooperate*, *exploit*,

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and *isolate*—similar to [16]. The *cooperators* help the other nodes in forwarding their messages. The *exploiters* use the other nodes as "free-riders", without helping them in forwarding their messages. The *isolators* neither take help, nor provide so, to the other nodes in forwarding their messages. It is pertinent to clarify at this juncture that the existing work [16] considers the above mentioned strategies. It, however, merely shows the existence of a cyclic equilibrium among the three strategies, cooperate, exploit, and isolate. Additionally, it studies the aspect of cooperation in opportunistic mobile networks, combining the concept of Rock-Scissors-Paper game, and Simpson's paradox. The current work, on the contrary, presents a distributed mechanism, using which each node dynamically selects the most successful strategy. Our mechanism prevents the nodes from selecting the exploit and isolate strategies, which, in turn, stimulates them to cooperate. The design of a mechanism for the enforcement of cooperation is new to this work. Further, in this work, we present the theoretical characterization of the proposed scheme together with extensive performance evaluations.

Evolutionary theory (ET) [17] postulates that each individual in a population periodically checks the alternative strategies and selects the best one for survival. Inspired by this, we consider an OMN, in which the nodes periodically compare their individual performance with the locally available network-wide performance (in terms of delivery ratio of messages) and switch to the strategy of the most successful group, if it is not the node's strategy already. We develop a *Distributed Information-baSed Cooperation UShering Scheme (DISCUSS)*, using which the nodes locally exchange information among themselves to acquire knowledge about the performance of one another, without requiring a central authority (CA) to do it. We show that the proposed scheme provides high delivery probability and low latency on message delivery. For evaluating the effectiveness of the proposed scheme, we proposed a variant of DISCUSS, in which the nodes are assumed to possess *global knowledge*—every node is assumed to possess precise information about the messages created and delivered by any node. In the rest of the manuscript, we refer to this variant as "DISCUSS with global knowledge".

The contributions of this paper are summarized in the following points:

- Proposing a scheme, inspired by evolutionary theory, following which the nodes dynamically adapt their message forwarding strategies based on distributed information over time.
- Proposing the distributed information based cooperation ushering scheme, DISCUSS, to promote cooperation amongst nodes for message forwarding through self-evaluation using their own and the network's performance information.
- Establishing the effectiveness of DISCUSS by evaluating the Jaccard similarity index [18] between DISCUSS and its variant, in which global knowledge is available.
- Analyzing the theoretical characteristics of the scheme in terms of complexity and convergence.
- Demonstrating the efficiency of the proposed scheme through extensive simulations using both real-life traces and synthetic mobility models.

The remaining part of this work is organized as follows. Section 2 presents a review of the related work. Section 3 provides an overview of the system model. This is followed by Section 4, in which we describe the proposed scheme, DISCUSS. Section 5 contains the theoretical description of the characteristics of DISCUSS. Sections 6 and 7 present the simulation setup and analysis of results. Finally, in Section 8, we conclude this work.

2 Related Work

The operation of message delivery in OMNs is generally reliant upon cooperation by intermediate nodes. Due to resource limitations, the intermediate nodes do not always want to help the other nodes. Each node in the network always tries to fulfill its own goal by utilizing the other node's resources. So, to promote cooperation between nodes in such type of networks, different cooperation-enforcing schemes [19] were proposed. Credit- and reputation-based approaches [9], [10], [11], [12], [13] are commonly known to promote cooperation among nodes. In the credit-based incentive schemes, virtual currency or pricing acts as the credit. On the other hand, in the reputation-based schemes, reputation of the nodes are calculated by their neighbors based on the message forwarding actions.

2.1 Credit-Based Schemes

Shevade et al. [10] first proposed a credit-based incentive mechanism for DTNs, which motivate the selfish nodes to cooperation. Their results show that the presence of selfish nodes degrade the overall network performance. To alleviate this behavior, they proposed the pair-wise Tit-for-Tat (TFT) incentive mechanism. They considered two constraints—generosity and contrition—to maximize cooperation among nodes. Zhu et al. [9] proposed SMART, a Secure Multilayer Credit based Incentive scheme for DTNs. SMART stimulates cooperation among nodes by preventing the malicious users from cheating credits based on layered coins. Layered coin provides virtual credits for charging and rewarding of data forwarding in DTNs. On the other hand, another scheme, MobiCent [11], provides incentive to the selfish nodes for forwarding other node's messages. Lu et al. [15] proposed the "Pi" protocol, where the selfish nodes are stimulated to cooperate by forwarding the messages of other nodes. Pi attaches incentives to the messages and sends it to the intermediate nodes, which attracts the participation of other nodes in forwarding. However, this method need a trusted authority for storing the credit and reputation of each nodes. "iTrust" [8] encourages cooperation among the forwarding intermediate nodes, by providing incentives, and detecting and punishing the misbehaving nodes. "iTrust" introduces the concept of a periodically accessible trusted authority, which detects the misbehaving nodes based on the forwarding history evidence.

2.2 Reputation-Based Schemes

MobiID [12] is a reputation-based incentive scheme. It assumes an offline system manager, where each node registers to join the network. This scheme uses self-check and community-check of either the previous-/next-hop nodes or their community before forwarding a message. A reputation value is assigned to the forwarding node, when it forwards a message to another node. Nodes are ostracized when their corresponding reputations are less than a given threshold. So, each node exerts itself to cooperate in forwarding other node's messages, in order to earn increased levels of reputation. Zhang et al. [13] proposed a practical reputation-based incentive "Pri" scheme. Pri also assumes the use of offline security manager (OSM), which is in charge of key distribution. Nodes register in OSM before joining the network.

Resta and Santi [20] analyzed the performance of epidemic routing for different degrees of node cooperation. They derived the probability distribution of packet delivery delay and communication cost. Communication cost is computed by determining the number of nodes having the message in the network by the timing a copy of the message is first delivered to the destination. Apart of these works, Buttyan et al. [21] and Yin et al. [22] proposed a non-cooperative game theoretic model that avoids selfish behavior among nodes and stimulates cooperation among individuals in a network. Elwhishi et al. [23] proposed a message scheduling framework for epidemic routing in DTNs, which improves the message delivery ratio.

From the above works, it can be *synthesized* that cooperation enforcement poses a great challenge in OMNs and requires the use of tamper-proof hardware for updating the reputation values of every node. Otherwise, for giving reward or punishment, the recipient nodes need to be traced, which is costlier in OMNs. On the other hand, the proposed approach does not need a central server or any incentive mechanism. On every contact, a node maintains and exchanges information with the other neighboring nodes, about the messages created and delivered in the network. Based on this local information, a node evaluates its own performance and compares it with the approximated network performance of others. A node adapts, other strategy, if its own performance is inferior than the others performance.

3 System Model

3.1 Assumptions

The proposed schemes "DISCUSS" and its variant "DISCUSS with global knowledge", makes the following assumptions:

1) Each node follows any one of these three message forwarding strategies at a time—*cooperate*, *exploit*, and *isolate*.
2) In the DISCUSS scheme, the nodes reliably exchange information with their neighboring nodes.
3) In case of DISCUSS with global knowledge, the nodes can obtain message delivery information from a central authority.
4) In DISCUSS with global knowledge, every node shares its relevant information with the CA. So, each node has "complete" information (number of generated and delivered messages) about the other nodes.

3.2 Strategy Defined-Opportunistic Mobile Network

We represent an OMN as (N, M, S), where N denotes the set of nodes in the network, M denotes the set of messages generated by the nodes, and S denotes the set of strategies selected by any node in forwarding the messages; $S = \{Cooperate, Exploit, Isolate\}$. Each node may act as a source, a destination or an intermediate relay node. We consider three groups of nodes—*cooperators*, *exploiters*, and *isolators*—based on these strategies. The following section elaborates the behavior of the individual nodes.

3.2.1 Cooperators

These nodes with the strategy "cooperate" not only forward their own messages, but help the other nodes as well in doing so. In other words, the cooperators act as relays by receiving, storing and forwarding the messages generated by the other nodes.

3.2.2 Exploiters

On the other hand, the *exploiters* forward their messages to the other nodes (cooperators) for delivery. They receive other node's messages, but instead of storing them, they silently drop those messages. The *exploiters* take help from others for forwarding their own messages as free riders, without helping them.

3.2.3 Isolators

The *isolators* only receive the message for which they are the destinations. They do not take help from the other nodes for forwarding their messages, neither do so for others. The *isolators* directly deliver their messages, when they meet with the corresponding destination node.

Definition 1. *An OMN is said to be* Strategy Defined-Opportunistic Mobile Network (SD-OMN), *if all the nodes in the OMN follow any message forwarding strategy described by the set $S = \{Cooperate, Exploit, Isolate\}$. At any point of time, a given node chooses only one strategy from S.*

Let n_C, n_E, and n_I, respectively denote the number of cooperators, exploiters, and isolators in the SD-OMN at time instant t. Therefore, we have $|N| = n_C + n_E + n_I$. The objective of SD-OMN is to motivate the non-cooperators in the network into cooperation in order to optimize the performance of the network. Therefore, the goal function can be write as,

$$\max_{t\in\mathbb{R}} n_C(t), \quad \text{s.t. } 0 < t \leq \Gamma,\ 0 < n_C(t) \leq |N|, \tag{1}$$

where, Γ is the lifetime of the system. When the concerned performance objective is the delivery ratio (i.e., the fraction of the created messages that have been delivered to their respective destinations) of the messages, the performance function should be maximized. Therefore, in this context, the goal function of this work, can be alternatively represented as,

$$\max_{t\in\mathbb{R}} \sum_{s\in S} \alpha_s(t), \quad \text{s.t. } 0 < t \leq \Gamma,\ 0 < \alpha_s(t) \leq 1, \tag{2}$$

where, $\alpha_s(t)$ denotes the delivery ratio of the group of nodes with strategy $s \in S$ at any time instant t. We validate this in Section 5.

3.3 Network Performance Information

Initially, each node has a message forwarding strategy. Each node distributively shares information with the other nodes, without requiring a CA. Each node has limited information about the effect of its actions. When two nodes mutually encounter, they interchange their past history (own delivered message list and nodes' delivery probability list) with the neighboring nodes. Based on the local knowledge of past history, each node updates its behavior. The nodes select their own communication mode—whether they *cooperate*, *defect* or *isolate* in message forwarding, based on their past history. In case of DISCUSS with global knowledge, we assume that all nodes are managed by a CA. The nodes share their relevant information such as received message ids, message sender node ids, and own delivery probability with the CA. Every node collects information such as delivery probabilities of the other nodes' from the CA. They select their own communication modes based on these information.

4 Distributed Information-Based Cooperation Ushering Scheme

We now discuss a scenario where a node dynamically switches its forwarding strategy, if required, to the most successful strategy in the concerned SD-OMN. This is inspired by the existing research in *evolutionary theory* [17], which shows that the size of groups in a population[1] changes with the various competing strategies. In particular, the following presents a mapping of the concepts from Darwin's Natural Selection Theory [24] into our context involving SD-OMN.

- Nodes in SD-OMN exhibit variation in their message forwarding actions.
- Such variation occurs as the nodes follow different kinds of strategies, as defined by the set S.
- The most successful strategy among the set S survives in the population and is propagated to the other nodes over time.

We present the proposed scheme, DISCUSS, in the backdrop of ET. Table 1 list the notations used to represent the system parameters with a short description.

DISCUSS comprises of two phases that are repeated in every generation interval (τ). (1) *Acquiring information* on the performance of the SD-OMN, and (2) *Strategy adaptation*. The first phase requires information on—(a) The messages created (CM) by the nodes, (b) The delivered messages (DM), and (c) The delivery probabilities (DP) of the nodes.

4.1 Acquiring Information

Let i and j be two nodes that come in contact with each other at time t. Let $\mathrm{CM}^i(t)$ be the list of generated messages by node i at time t. Then,

1. Population in ET and set of nodes in our case.

TABLE 1
List of Notations

CM^i_t	Created messages list of the node i at time t
DM^i_t	Delivered messages list of the node i at time t
DP^i_t	Delivery probability list of the node i at time t
Ψ_g	Group weight of the group g
$\Psi^i(t)$	Group weight of the node i at time t
p^i_k	Delivery probability of k^{th} node of node i
t_k	Time stamp of k^{th} node
α^i_g	Delivery probability of the group g, $g \in \{C, E, I\}$, as known by the node i
ω^i_g	Weighted factor of the group g, $g \in \{C, E, I\}$, as computed by the node i
γ^i_g	Weighted average delivery ratio of group g, $g \in \{C, E, I\}$, as computed by the node i

$$CM^i(t) = \{(m^i_r, t_r)\},$$

where m^i_r is the rth message created by the node i, at time t_r, $r \geq 0$. In other words, $CM^i(t)$ consists of the list of messages created by node i till time t. Similarly, we define $DM^i(t)$ as:

$$DM^i(t) = \{(m^i_q, t_q)\},$$

where m^i_q is the qth delivered message of the node i at time t_q. Therefore, $DM^i(t) \subseteq CM^i(t)$.

Each node i maintains its own delivery probability, as well as its view of the other nodes' delivery probabilities known till time t in DP^i_t as:

$$DP^i_t = \{(k, p^i_k, t^i_k)\},\ k = 1 \text{ to } N,\ t \geq t_k, \forall k.$$

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Here, p^i_k is the last updated information stored at node i on the delivery probability of the node k known at time t_k. The delivery probability (p_k) of any node k, $\forall k \in N$, is determined as:

$$p_k = \frac{|DM^k(t)|}{|CM^k(t)|}. \tag{3}$$

Information are updated between pairs of nodes, when they come within their respective communication ranges. More specifically, node i, $i \in N$, maintains a list of delivery probabilities for every node it has met before. Delivery probability (p^i_k) of the list DP^i_t is updated in every connection, according to the following rule:

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$$p^i_k = \begin{cases} p^j_k, & \text{if } t^j_k > t^i_k, \\ p^i_k, & \text{otherwise.} \end{cases} \tag{4}$$

Algorithm 1 describes the steps required for updating node i's lists on encountering node j, $\forall i, j$.

Fig. 1 illustrates an example of comparison and update process of two nodes i and j. On every contact, node i updates its information with node j, as given below.

- Node i has three lists CM^i, DM^i, and DP^i, at time t. Similarly, node j has CM^j, DM^j, and DP^j.
- Node i generates two messages, $M8$ and $M12$, at $t = 150$ and 200 s, respectively. Similarly, node j has messages $M24$ and $M5$ created at $t = 321$ and 101 s, respectively.

- Nodes i and j list the past delivered messages of nodes. Node i checks node j's list of delivered message, and updates its own list of delivered messages. Initially, nodes i and j have $DM^i = \{\langle M8, 400\rangle, \langle M2, 700\rangle\}$ and $DM^j = \{\langle M24, 800\rangle\}$. After updating, node i has $DM^i = \{\langle M8, 400\rangle, \langle M2, 700\rangle, \langle M24, 800\rangle\}$.
- Node i finds its delivery probability (p_i) at current time t as $p_i = |CM^i|/|DM^i|$, and updates its delivery probability list.
- Node i compares its own DP^i list with the jth node's DP^j list, and then updates its list.
- Let node i choose the kth node time stamp (t_k^i) from the DP^i list, and compare it with the kth node's time stamp (t_k^j) of node j's DP^j list. If $t_k^i < t_k^j$, node i updates its kth node's delivery probability by dp_k^j. Node i checks the 1st node's time instant, i.e., $300 > 0$, and consequently makes no change. Again, it checks the 2nd node's time instant, i.e., $400 < 800$, and then updates the message delivery probability of this node by 0.5. Similarly, it repeats this for the rest of the nodes of node i. Hence, $DP_t^i = \{\langle 0.2, 300\rangle, \langle 0.5, 800\rangle, \langle 0.3, 600\rangle\}$.

Algorithm 1 repeats exactly in the same way as described for updating the list of other nodes.

Algorithm 1: Delivery probability update by node i on contact with node j

Inputs : $CM_t^i, CM_t^j, DM_t^i, DM_t^j, DP_t^i, DP_t^j$
Output: Updated values of DM_t^i and DP_t^i

$C \leftarrow |CM_t^i|$; `// Number of messages in` CM^i
$D \leftarrow |DM_t^j|$; `// Number of messages in` DM^j
`/* Check, whether` DM^j `list contain any created messages of node` i`. If so, add it to` DM^i`. */`
for $u \leftarrow 1, C$ **do**
    for $v \leftarrow 1, D$ **do**
        if $(m_u = m_v)$ **then**
            Add m_v to DM_t^i;
        end
    end
end
`// Find delivery probability of` i `and` j
$DP_t^i \leftarrow |DM_t^i|/|CM_t^i|$;
$DP_t^j \leftarrow |DM_t^j|/|CM_t^j|$;
$P_i \leftarrow |DP_t^i|$; $P_j \leftarrow |DP_t^j|$;
`/* Node` i `compare its own DP list with node` j`'s DP list */`
for $u \leftarrow 1, P_i$ **do**
    for $v \leftarrow 1, P_j$ **do**
        if $t_k^v > t_k^u$ **then** `/* Compare time stamp of` k^{th} `node at node` i `and the same` k^{th} `node at node` j`. */`
            $p_k^u \leftarrow p_k^v$, $t_k^u \leftarrow t_k^v$; `/* Update delivery probability and time stamp of` k^{th} `node at node` i `*/`
        end
    end
end

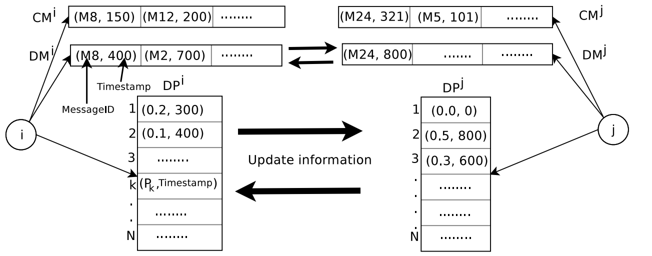


Fig. 1. Update information on each contact.

Further, each node i, $i \in N$, maintains a record of the group weights, $\Psi_g^i(t)$, $g \in \{C, E, I\}$. Initially, at time $t = 0$, $\Psi_g^i(t)$ is empty. At any time t, when a node i comes in contact with another node j belonging to a group g, where $g \in \{C, E, I\}$, node i updates its value of the corresponding group weight as:

$$\Psi_g^i(t) = \Psi_g^i(t-1) + \mathbb{I}_g^i(t), \tag{5}$$

where, $\mathbb{I}_g^i(t)$ is the indicator decision variable, which, in turn, is defined as follows:

$$\mathbb{I}_g^i(t) = \begin{cases} 1, & \text{if node } i \text{ receives a message from group } g, \\ 0, & \text{otherwise.} \end{cases}$$

For example, $\Psi^i(t) = \{\Psi_C^i, \Psi_E^i, \Psi_I^i\}$ indicates that until the time instant t, node i receives Ψ_C^i, Ψ_E^i and Ψ_I^i number of messages, respectively, from the cooperators, exploiters, and isolators, respectively. Thus, Ψ_g denotes the relative importance of each group over the others.

4.2 Strategy Adaptation

Cooperation is necessary and important in OMNs for increasing the performance of the networks. So, for enhancing cooperation among nodes, we propose a dynamic *strategy adaptation* mechanism. This mechanism bridges the nodes' self-recommendation approach based on the local information gathered by a node during contacts with other nodes. The objective of the proposed approach is to maximize the expected delivery probability of messages in the Kth time-slots by motivating the exploiters and isolators to shift their strategies to cooperation.

We evaluate the proposed approach using two scenarios: *static* and *dynamic*. In the *static* scenario, the number of cooperators (n_C), exploiters (n_E), and isolators (n_I) remain invariant over time t, i.e.,

$$\left.\begin{aligned} n_C(t) &= n_C(0), \\ n_E(t) &= n_E(0), \\ n_I(t) &= n_I(0), \end{aligned}\right\} \tag{6}$$

and $n_C + n_E + n_I = |N|, \ \forall t$.

In the *dynamic* scenario, the number of cooperators (n_C), exploiters (n_E), and isolators (n_I) vary with time. A *generation* is a stage in the life cycle of a node. The strategies of individuals (nodes) remain same in a *generation*. The *generation interval* (τ), where $\tau = \{1, 2, 3, \ldots, K\}$, is the time required to complete a generation. In Fig. 2, initially, the size of cooperators, exploiters and isolators are the same. After a *generation interval*, every node

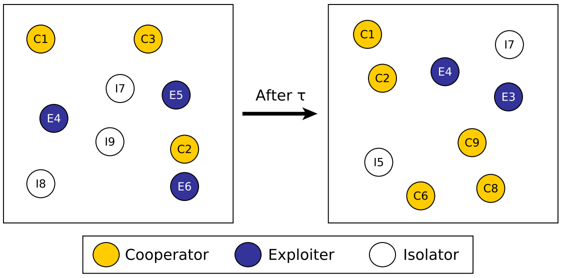


Fig. 2. Strategy adaptation by the nodes in the SD-OMN after a generation interval (τ).

compares its individual performance with that of the other groups, and dynamically changes its strategy, if required, accordingly. Such a self–evaluation can be performed by each node individually during the run-time based on information exchanged with the other nodes, as discussed below.

Each node i has a delivery probability list (DP_t^i), where it stores the delivery probabilities of the other nodes based on the most recent information available, together with the corresponding time when the information was obtained, and then time stamps it. Any node i, $i \in N$, computes the average delivery ratio α_g, $g \in \{C, E, I\}$ of cooperators, exploiters, and isolators, as follows:

$$\left.\begin{aligned} \alpha_C^i &= \frac{\sum_{k\in N_C} p_k^i}{|N_C|} \\ \alpha_E^i &= \frac{\sum_{k\in N_E} p_k^i}{|N_E|} \\ \alpha_I^i &= \frac{\sum_{k\in N_I} p_k^i}{|N_I|} \end{aligned}\right\}, \tag{7}$$

where, α_C, α_E, and α_I, respectively, denote the average delivery ratio of the cooperators, exploiters, and isolators in the OMN. Here, N_C, N_E, and N_I denote the set of cooperators, exploiters, and isolators that node i, $i \in N$, met within time interval τ.

Definition 2. *The weighted factor, ω, of a group g, $g \in \{C, E, I\}$ is defined as:*

$$\omega_g = \frac{\Psi_g}{\sum_{s\in\{C,E,I\}} \Psi_s}.$$

Node i determines the *weighted factor* of each group from $\Psi^i(t)$. The weighted factor of cooperators (ω_C^i), exploiters (ω_E^i), and isolators (ω_I^i) of node i are calculated using Definition 2, as follows:

$$\left.\begin{aligned} \omega_C^i &= \frac{\Psi_C^i}{\Psi_C^i+\Psi_E^i+\Psi_I^i} \\ \omega_E^i &= \frac{\Psi_E^i}{\Psi_C^i+\Psi_E^i+\Psi_I^i} \\ \omega_I^i &= \frac{\Psi_I^i}{\Psi_C^i+\Psi_E^i+\Psi_I^i} \end{aligned}\right\}. \tag{8}$$

Definition 3. *The weighted average message delivery ratio γ_g of a group g is defined as:*

$$\gamma_g = \alpha_g \times \omega_g. \tag{9}$$

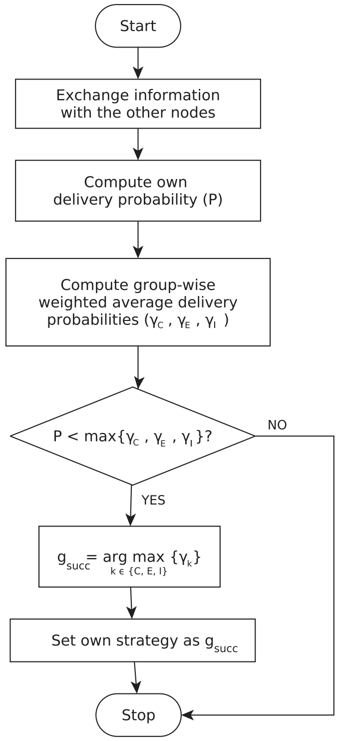


Fig. 3. Flowchart depicting the steps in DISCUSS.

From Definition 3, the *weighted average delivery ratio* of cooperators (γ_C), exploiters (γ_E), and isolators (γ_I) of node i is calculated as follows:

$$\left.\begin{aligned} \gamma_C^i &= \alpha_C^i \times \omega_C^i \\ \gamma_E^i &= \alpha_E^i \times \omega_E^i \\ \gamma_I^i &= \alpha_I^i \times \omega_I^i \end{aligned}\right\}. \tag{10}$$

Finally, node i determines the most successful group, g_{succ}, as follows:

$$g_{succ} = \begin{cases} \text{C}, & \gamma_C > \gamma_E,\ \gamma_C > \gamma_I \\ \text{E}, & \gamma_E > \gamma_C,\ \gamma_E > \gamma_I \\ \text{I}, & \gamma_I > \gamma_E,\ \gamma_I > \gamma_C \end{cases} \tag{11}$$

Now, node i changes its group to g_{succ}, if its delivery probability, computed using Equation (3), is less than the maximum of the weighted average delivery ratio of the three groups, i.e.,

$$p_i < max(\gamma_C^i, \gamma_E^i, \gamma_I^i). \tag{12}$$

The strategy adaptation mechanism is repeated exactly in the same way for every node after each *generation interval* for switching to a successful strategy. In particular, we note that, if a node fails to perform self-evaluation due to one reason or another (for example, when a node does not have information about the other nodes available yet), it continues with its own previous strategy. The flowchart presented in Fig. 3 shows the sequence of steps performed by a node executing the DISCUSS algorithm in an OMN.

5 CHARACTERISTICS OF DISCUSS

This section presents the complexity analysis and theoretical analysis on the characteristic of DISCUSS.

分析 才是 本文之重点！

5.1 Theoretical Analysis

Definition 4. *A SD-OMN with N nodes is said to have reached an* equilibrium, *when* $(1-\delta)N$ (where $0 \leq \delta < 1$) *nodes have a common strategy, $s \in S$, and the remaining δN nodes have different strategy/strategies. The common strategy of the $(1-\delta)N$ nodes is said to be the* equilibrium strategy.

Definition 5. *A SD-OMN is said to have reached* (K, δ) convergence, *if, for K successive generations, where $K \geq 1$, at least the $(1-\delta)N$ nodes have the same common strategy, $s \in S$, while the remaining nodes could possibly have different strategy/strategies.*

Theorem 1 (Necessary Criteria for (K, δ) Convergence). *Let s_i be the equilibrium strategy at the i^{th} generation. If $s_i = s_j$, $\forall i$, $j \in \{1, 2, \ldots, K\}$, SD-OMN has attains (K, δ) convergence.*

Proof. The proof follows from Definition 5. □

Theorem 2 (Sufficient Criteria for (K, δ) Convergence). *Let s_i be the equilibrium strategy for the ith generation. It is sufficient to say that SD-OMN moves toward (K, δ) convergence with $\delta \rightarrow 0$, when,*

均衡策略=>收敛

$$\gamma_{s_i} \gg \max_{s_i}\{\gamma_{s_i'}\}, \; s_i' \in S - \{s_i\}.$$

Proof. Let N_{s_i} be the set of nodes with strategy s_i, and $N_{s_i'}$ be the set with strategies other than s_i. Using Equation (9), we have,

$$\gamma_{s_i} = \sum_{n \in N_{s_i}} \alpha_{s_i}^n \omega_{s_i}^n.$$

Assuming, $\gamma_{s_i} \gg \gamma_{s_i'}$, we have

$$\sum_{n \in N_{s_i}} \alpha_{s_i}^n \omega_{s_i}^n \gg \sum_{n \in N_{s_i'}} \alpha_{s_i'}^n \omega_{s_i'}^n$$

$$\Rightarrow \sum_{n \in N_{s_i}} \alpha_{s_i}^n \Psi_{s_i}^n \gg \sum_{n \in N_{s_i'}} \alpha_{s_i'}^n \Psi_{s_i'}^n$$

可能不严谨 没有办法直接推导出这样的结论

$$\Rightarrow \sum_{n \in N_{s_i}} \frac{p_{s_i}^n}{|N_{s_i}|} \Psi_{s_i}^n \gg \sum_{n \in N_{s_i'}} \frac{p_{s_i'}^n}{|N_{s_i'}|} \Psi_{s_i'}^n.$$

The above holds true if any one of the following conditions holds: (1) $|N_{s_i}| \gg |N_{s_i'}|$, (2) individual $\alpha_{s_i}\Psi_{s_i} \gg \alpha_{s_i'}\Psi_{s_i'}$, (3) both (1) and (2). Let us look at the individual cases.

Case 1:

$$|N_{s_i}| \gg |N_{s_i'}|$$

$$\Rightarrow \frac{|N_{s_i}|}{|N_{s_i'}|} \gg 1$$

$$\Rightarrow \frac{|N_{s_i}| + |N_{s_i'}|}{|N_{s_i'}|} \gg 1$$

$$\Rightarrow \frac{1}{\delta} \gg 1 \Rightarrow \delta \ll 1 \Rightarrow \delta \rightarrow 0.$$

This implies that SD-OMN moves towards convergence.

Case 2: $\alpha_{s_i}\Psi_{s_i} \gg \alpha_{s_i'}\Psi_{s_i'}$ implies that most of the nodes from $N_{s_i'}$ switch to N_{s_i}, which, in turn, implies that in the next generation, SD-OMN will attain convergence.

Case 3: If both Cases (1) and (2) occur, SD-OMN will attain convergence. Hence, the proof. □

Theorems 1 and 2 bear significance in the characterizability of the convergence time of strategies in the concerned SD-OMN. In other words, for given K and δ, one can determine if and when the OMN converges to an equilibrium strategy. This is revisited in Section 7 in the context of experimental results.

Theorem 3. *The message delivery ratio of the SD-OMN increases with the increasing number of cooperators. Mathematically,*

他的定义 比较奇怪。。。
真的投递率不太能说得过去。。。

$$lim_{|N_C| \rightarrow |N|} \sum_{s \in S} \alpha_s(t) = 1.$$

Proof. Let $|N_C| \gg |N_{s'}|$, where $s' \in S - \{C\}$. The chances of message delivery for a group g increases with the increase in the corresponding Ψ_g. So, we can approximate α_s as

$$\alpha_s(t) \approx \frac{\Psi_s}{\sum_{s \in S} \Psi_s}.$$

As the number of cooperators is high, Ψ_C is also high, since the cooperators forward the messages of exploiters as well. So, we can write $\Psi_C \gg \Psi_{s'}$. Therefore,

$$\alpha_C(t) = \frac{\Psi_C}{\sum_{s \in S} \Psi_s} \approx \frac{\Psi_C}{\Psi_C} = 1.$$

Moreover, as $\Psi_{s'} \rightarrow 0$, $\alpha_{s'} \rightarrow 0$, $s' \in S - \{C\}$. Therefore,

$$\sum_{s \in S} \alpha_s(t) = \alpha_C(t) + \sum_{s' \in S - \{C\}} \alpha_{s'}(t) = 1.$$

Hence, the proof. □

Theorem 3 holds true in a SD-OMN, when one of the following conditions is satisfied.

1) The traffic generation rate is low, but messages are generated throughout the lifetime of the system considered.
2) The traffic rate is high and messages are generated for a short period of time (possibly during the initial generation of the SD-OMN).

In the first case, due to low traffic rate, less number of messages are generated in the time period considered. Theoretically, almost all of them can be delivered to the respective destination if most of the nodes are cooperators, so that $lim_{|N_C| \rightarrow |N|} \sum_{s \in S} \alpha_s(t) = 1$. In reality, depending on the contact patterns among the nodes, the same may be less than unity. In the second case, although more messages are created in the system, a comparatively longer lifetime allows the delivery of most of them. Again, when most of the nodes are cooperators, $lim_{|N_C| \rightarrow |N|} \sum_{s \in S} \alpha_s(t) = 1$. Moreover, this theorem verifies the goal function presented in Equation (2).

The case of high traffic rate, however, deserves further discussion. In real life, there are practical constraints on the buffer capacity of the nodes and/or lifetime of the messages. Even if such constraints are relaxed, continuous generation of messages throughout the lifetime of the system does not provide sufficient time to the nodes to deliver them using the store-carry-and-forward approach that is

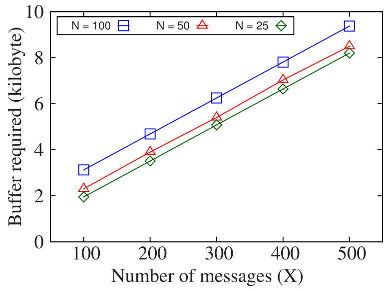


Fig. 4. Storage overhead of DISCUSS as a function of the number of messages.

typical of OMNs. This can be realized from the fact that in OMNs, the average message delivery latency is typically a few thousand seconds, or may be more. Therefore, in such cases, the claim of Theorem 3 can be sub-optimal.

5.2 Complexity Analysis

Space complexity. Each node caches the CM, DM, and DP lists in its buffer. Let σ, φ, λ, and μ bytes be required to store a node's address, message identity, time stamp, and delivery probability, respectively. Let us further assume that a node generates X number of messages, out of which Y messages are delivered. Let N be the total number of nodes in the SD-OMN. We compute the space required for storing X messages in CM and Y messages in DM. The space complexity for storing CM, DM, and DP at the nodes, respectively, are

$$\mathcal{S}(CM) = X \times (\varphi + \lambda) \in O(X), X \gg (\varphi + \lambda),$$
$$\mathcal{S}(DM) = Y \times (\varphi + \lambda) \in O(Y), Y \gg (\varphi + \lambda),$$
$$\mathcal{S}(DP) = N \times (\sigma + \mu + \lambda) \in O(N), N \gg (\sigma + \mu + \lambda).$$

So, the space complexity for storing these lists in a node is $O(n)$, where $n = X + Y + N$. As an illustration, let $\sigma = 8$ byte (typical for Bluetooth hardware address), $\varphi = \lambda = \mu = 4$ byte and $N = 100$. So, the size of the list DP is, $|DP| = 100 \times (8 + 4 + 4) = 1{,}600$ byte. Similarly, $|CM| = 8X$ byte, and $|DM| = 8Y$ byte. So, the total buffer overhead, $B = 1,600 + 8(X + Y)$ byte. With $X = Y = 100$, $B = 3{,}200$ byte. Fig. 4 shows the buffer requirement versus the number of messages for storing the lists, when $X = Y$. This is insignificant, given the fact that today's smart phones have storage capacities ranging upto a few gigabytes.

Time complexity. The time complexity of Algorithm 1 is $\max\{O(XY), O(N^2)\} = O(m^2)$, where $m = N$ or $m =$ number of messages created or delivered. Thus, the time complexity is quadratic in terms of the number of nodes in the network, or the number of messages created and delivered – whichever is maximum. The most time consuming part of DISCUSS algorithm (as shown in Fig. 3) is the phase of acquiring information, which is described in Algorithm 1. The remaining steps of the DISCUSS algorithm are linear or constant, and do not affect the order of complexity. So, the time complexity of DISCUSS is $O(m^2)$.

5.3 DISCUSS with Global Knowledge

For the sake of completeness and evaluating the effectiveness, we also consider a version of DISCUSS, where the nodes have complete information about the SD-OMN. In this case, we assume the presence of a central authority in the network, with which the nodes can communicate instantaneously. Whenever a new message is created (or delivered), the CA is informed by the concerned node. Based on these information, the CA computes the DP of each node. At the end of each τ, all the nodes get the DP information of all the nodes in the network from the CA. Based on this, the nodes adapt their strategies to the most successful one, if required.

6 Simulation Design

This section gives the overview of the simulation setup, data sets, and metrics used for evaluation.

6.1 Simulation Setup

We evaluated the DISCUSS scheme using the ONE simulator [29] considering the synthetic mobility traces, *Helsinki City Map* (HCM) and *random way point* (RWP), together with the real-world traces, as summarized in Table 2. For the HCM and RWP mobility models, we executed the simulations for two days with 100 mobile nodes deployed in terrains of size $4{,}500 \times 3{,}400$ m^2 and 450×340 m^2, respectively, moving at a speed of 0.5-1.5 m/s. Messages were generated uniformly at random between every 30-40 seconds, with two randomly chosen nodes as the source-destination pair. The message size was chosen to be 25 KB and the Time-to-Live (TTL) of the messages was 5 hours. Each node had a buffer size of 3 MB, transmission speed of 250 Kbps, and transmission range of 10 meter.

The nodes used the binary Spray and Wait [3] routing protocol with maximum 10 copies per message. However, it is important to point out that the proposed approach is also applicable to other routing schemes.

At the beginning of the simulation, each node was assigned to an initial strategy from the strategy set S, in

TABLE 2
Data Sets

Dataset	Mobility type	Device	Network type	No. of devices	Duration (days)
Infocom06 [25]	Real	iMote	Bluetooth	78	4
PMTR[2] [26]	Real	PMTR	RTX-RTLP	44	19
Sassy [27]	Real	T-mote	Bluetooth	27	79
KAIST [28]	Real	T-mote	GPS receiver	4 (92-trace)	78
HCM [29]	Map-based	-	Bluetooth	100	5
RWP [29]	Random way point	-	Bluetooth	100	5

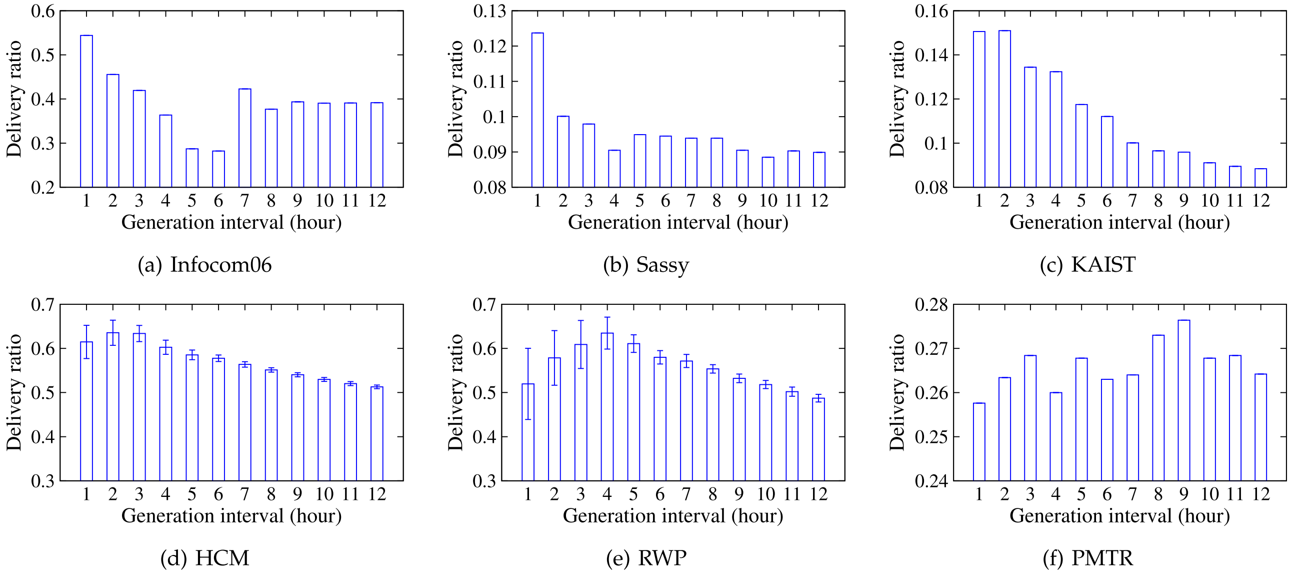


Fig. 5. Message delivery ratio for different generation intervals.

such a way that the percentage of the nodes having each strategy was equal. In the static scenario, the nodes do not change their respective strategies. On the other hand, in the dynamic scenario, at the end of each generation interval, the nodes decided whether or not to change their respective strategies. Based on the information available at the end of every generation interval (τ), each node determined the most successful strategy and switched to it if its strategy was not already the same. Unless otherwise specified, the generation interval was taken to be 1 hour.

The average value of the results taken over 30 runs together with the corresponding 95 percent confidence intervals are reported.

6.2 Performance Metrics

We evaluated the performance of the proposed scheme, DISCUSS, using the following metrics.

6.2.1 Group Composition (Size)

The percentage of cooperators, exploiters, and isolators in each generation with respect to time.

6.2.2 Delivery Ratio of Messages

It is the ratio of the total number of messages successfully delivered to the intended destination nodes to the total number of messages generated in the OMN.

6.2.3 Average Message Delivery Latency

It is the average time taken for delivering a message from the source node to its corresponding destination node.

We also compared the results of performance evaluation obtained for three variants of the DISCUSS algorithm: (a) DISCUSS in a dynamic scenario (referred to as "dynamic" in the plots), (b) DISCUSS in a static scenario (referred to as "static" in the plots), and (c) DISCUSS with global knowledge, as discussed in Section 5.3 (referred to as "global" in the plots).

7 Simulation Results

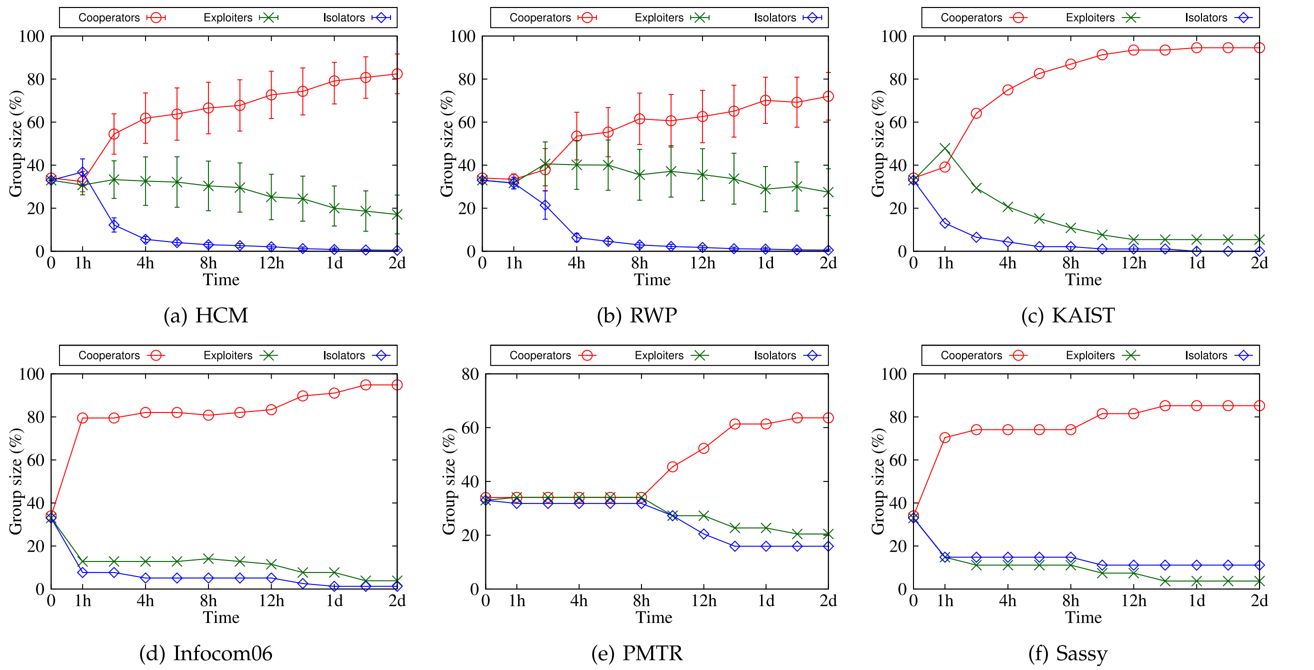
The results obtained in this manuscript are derived considering the data sets given in Table 2. In this Section, we present some results of DISCUSS using the metrics given in Section 6.2.

7.1 Effects of Generation Interval

Fig. 5 shows the delivery ratio of messages for different mobility scenarios and different generation intervals (τ). In the KAIST and RWP mobility scenarios, the message delivery ratio was higher when $\tau = 1$ hour, and it decreased as τ increased. This is because, as τ increased, the number of exploiters and isolators remained the same in respective strategies for τ time. So, the message drops increased in the OMN. It was observed that in 1 hour, almost all nodes had information about the other nodes. So, they attempted to switch their respective strategies. The sooner they changed their strategies, the better they earned in terms of delivery ratio. So, the overall network-wide message delivery increased, as the generation interval was less. Similarly, using the Infocom06 trace as well, the message delivery ratio increased when $\tau = 1$ hour. But in the HCM scenario, the delivery ratio improved marginally, when $\tau = 2$ hour, because in this case, in the 1st hour, the number of direct contacts was more than the indirect contacts, which implies that almost all messages of nodes are delivered. So, less number of nodes changed their strategies. This is ascribed to the fact that delivery ratio was high when $\tau \approx 1$ hour. So, hereafter, we consider $\tau = 1$ hour for all simulations. We present the experimental results using the map-based (HCM), random way point mobility model and real mobility traces (Infocom06 [25], KAIST [28], Sassy [27], and PMTR [26]).

7.2 Similarity Measurement

Similarity index is used to determine the similarity between two documents. Using this metric, we established the effectiveness of DISCUSS by comparing it with its variant, in



(a) HCM (b) RWP (c) KAIST

(d) Infocom06 (e) PMTR (f) Sassy

Fig. 6. Variation in group composition with time.

which global knowledge is available. Jaccard similarity index has been widely used in several works related to DTNs such as in the work by Hui and Crowcroft [30] as well as, wireless networks [31], in general. The application of Jaccard similarity index is suitable to evaluate the similarity of two sets, as considered here, unlike many other similarity indices such as, cosine similarity index, which operates upon two vectors. Let, after a generation interval, N_D and N_G, respectively, be the set of nodes using DISCUSS and its variant with global knowledge. In particular, $|N_G| = |N_D| = |N|$; N_G and N_D differ only in terms of the strategies adapted by the different nodes, e.g., node i may have strategy C in N_G, and E in N_D. Then, the Jaccard similarity index [18] is defined as:

$$J_s = \frac{|N_G \cap N_D|}{|N_G \cup N_D|}. \tag{13}$$

A measure of $J_s \in [0, 1]$ indicates the closeness in performance of DISCUSS with local and global knowledge.

Fig. 7 shows the similarities between DISCUSS with global and local knowledge for different time intervals. It was observed that the value of Jaccard similarity index increased with time, since the nodes obtained more accurate information as time increased. For the Infocom06, HCM, KAIST, and RWP data sets, the Jaccard similarity index was observed to be above 85 percent at the end of two days. However, for Sassy and PMTR, the similarities varied between 55 to 70 percent. In RWP, initially, in the 1st hour, very less number of nodes changed their strategies. So, the similarity is higher at the beginning. In RWP, the nodes met less frequently and for short durations. Therefore, using the DISCUSS scheme, the nodes did not exhibit accurate possessing information about other groups. So, the similarity decreased significantly (30 percent) between 1 to 10 hours using RWP.

7.3 Effects on the Group Composition

Fig. 6 shows the variation in group composition with time. Initially, in all the simulation scenarios, the percentages of cooperators, exploiters, and isolators were the same. In all the scenarios, the residual number of cooperators varied between 85-100 percent and the number of exploiters and isolators varied between 0-10 percent, except for the PMTR case. Using the PMTR trace, the percentage of cooperators, exploiters, and isolators were 78, 18, and 4 percent, respectively. We observed from Fig. 6 that the group size of the cooperators increased with time. The reason behind this is that, generally, the weighted delivery ratio (Equation (10)) of the cooperators is more, because the cooperators help in forwarding other nodes' messages. So, after each generation interval, more nodes switched their strategy to cooperate, instead of exploit and isolate. Another interesting phenomenon that was observed is that for all the traces,

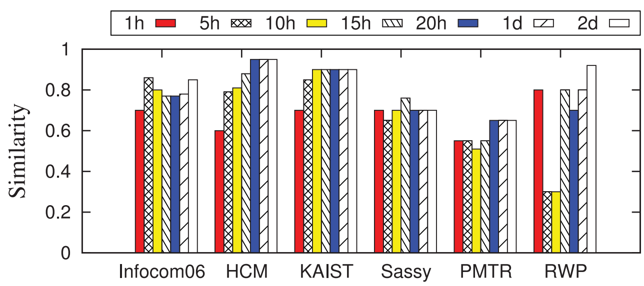
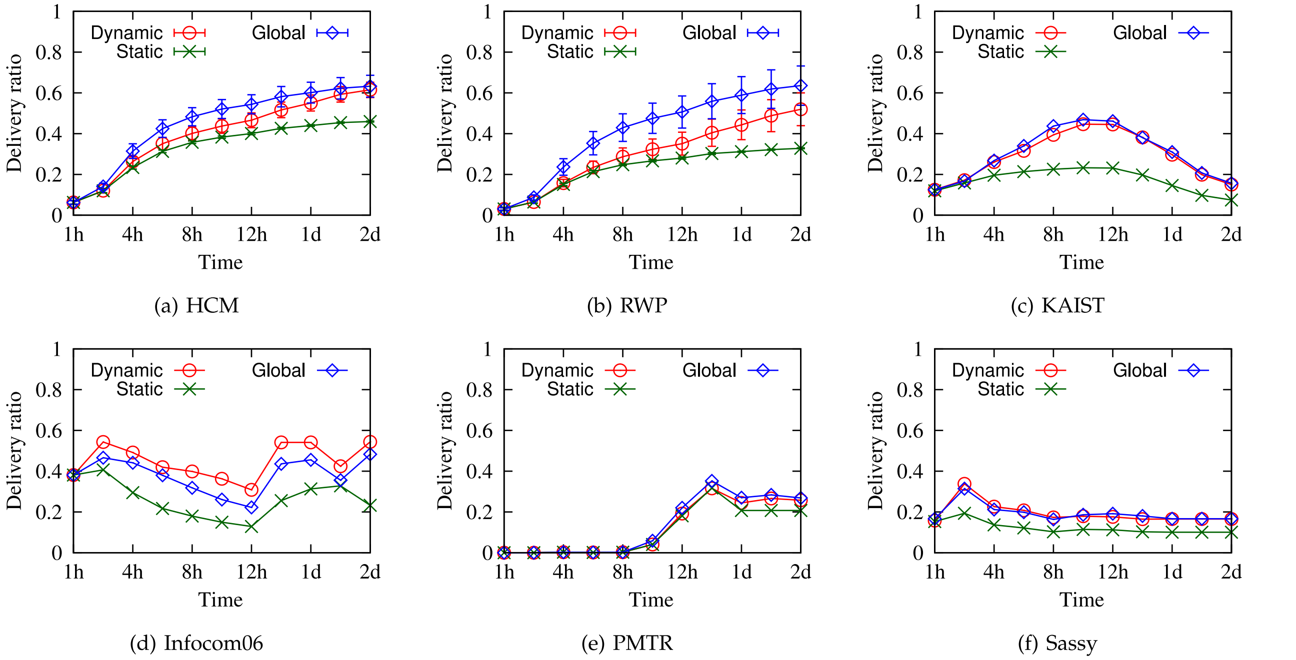


Fig. 7. Jaccard similarity index between DISCUSS and its variant with global knowledge.



(a) HCM (b) RWP (c) KAIST

(d) Infocom06 (e) PMTR (f) Sassy

Fig. 8. Message delivery ratio using DISCUSS in different scenarios.

approximately after one day, 80 percent nodes chose cooperation as their strategy because cooperate is the most successful strategy. In the HCM, RWP, KAIST, and Infocom06 traces, the number of isolators reached 0 percent after one day and number of exploiters reached 2-3 percent, except in the case of the HCM and PMTR traces.

(K, δ) convergence. From Fig. 6a, it can be observed that beyond 24 hour, the percentage of cooperators is at least 91 percent. Let us consider the time duration between 24 hour and 36 hour consisting of 12 generations, with $\tau = 1$ hour. We can infer from Fig. 6d that the SD-OMN attained (K, δ) convergence, with $K = 12$ and $\delta = 0.1$. Similar inferences can be drawn from others as well.

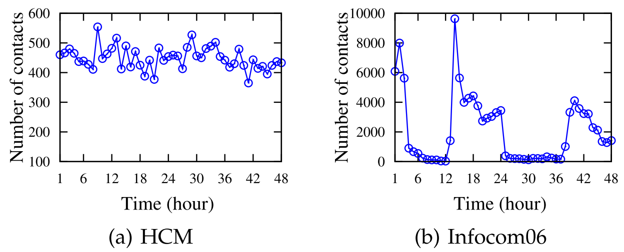
7.4 Delivery Ratio of Messages

We evaluated DISCUSS with respect to the *static*, *dynamic*, and *global* scenarios. Fig. 8 shows the cumulative delivery ratio as a function of time. Here, first we discuss the comparison of DISCUSS in the static and dynamic scenarios, and then we discuss DISCUSS in the global and dynamic scenarios.

It can be observed that in all the mobility traces, DISCUSS, in the dynamic scenario exhibited higher delivery ratio, than in the static scenario. For example, in the Infocom06 and HCM traces, the dynamic scenario outperformed the static one by 31 and 17 percent, respectively, at the end of two days. The reason behind this is that, in the static scenario, the group-wise percentage of nodes remained the same throughout the simulation. As discussed earlier, exploiters and isolators do not cooperate in forwarding other nodes' messages. So, the message drop probability increased over time and the delivery probability decreased for the static scenario. On the other hand, in the dynamic scenario, the group-wise percentage of nodes changed over time and most of the nodes switched their strategy to cooperate. Hence, the message delivery ratio increased over time.

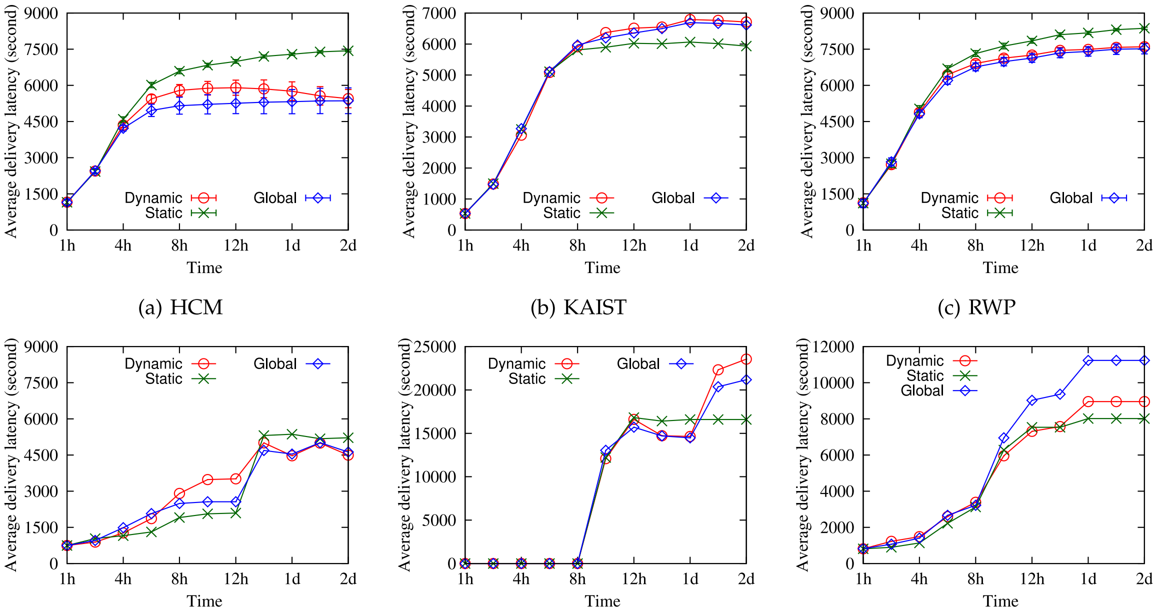
Further, in the Infocom06 trace, the message delivery ratio was less between 2-12 hours, because during this time, the number of contacts per hour was quite less, as shown in Fig. 9b. So, during this time, less number of messages were delivered to the destination nodes. However, in the HCM mobility trace, as shown in Fig. 9a, the number of contacts varied between 350 to 550, which is nearly similar throughout the simulation duration. So, the probability of message delivery increased over time when the cooperators increased with time. In KAIST mobility trace, the message delivery ratio decreased after 12 hour, because the number of contacts was observed to be less among nodes, in between 12-48 hour and message generation rate was uniform throughout the simulation duration. The delivery ratio of RWP, KAIST, PMTR, and Sassy were 51, 15, 25, and 16 percent respectively, due to assorted number of contacts on different mobility scenarios.

We compared the delivery ratio of the messages in global and dynamic scenarios. For the global scenario, accurate and same information were possessed by all the nodes and each node took decision accordingly. This implies that the delivery ratio for the global case is more accurate than the distributed case in the dynamic scenario. In the KAIST, PMTR, and Sassy scenarios, the delivery ratio was almost similar for both the global and dynamic scenarios, as the



(a) HCM (b) Infocom06

Fig. 9. Number of contacts in the network.



(a) HCM (b) KAIST (c) RWP

(d) Infocom06 (e) PMTR (f) Sassy

Fig. 10. Message delivery delay using DISCUSS in different scenarios.

number of contacts between nodes were higher and repetitive. In RWP, the delivery ratio of DISCUSS, in the global scenario was more than that in the dynamic scenario, because in the later case, the nodes did not get the complete information about the other groups of nodes due to less number of contacts. However, in the HCM scenario, the contacts were more and repetitive. Initially, the nodes had partial information about network performance. As time progressed, they came in contact with more number of nodes. So, the delivery ratio in the case of the dynamic scenario was almost the same as that of the global scenario after one day. Similarly, in the Infocom06 scenario, the delivery probability of the dynamic scenario was approximately the same as that in the global scenario.

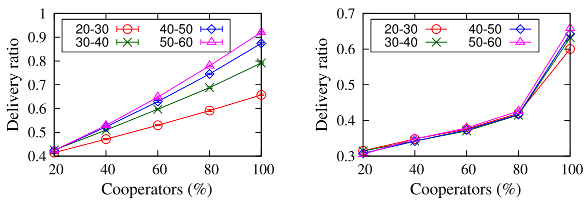
Fig. 11 shows the delivery ratio of the messages in SD-OMN, under light traffic load, which validates the claim of Theorem 3. Here, the message generation duration was taken as 1 day. We considered the SD-OMN with static scenarios, by varying the percentage of cooperators and message generation rates. It is observed from Fig. 11 that as the percentage of cooperators increased, the delivery ratio of the messages increased, correspondingly, towards unity.

7.5 Message Delivery Latency

Fig. 10 shows the average delivery delay of the messages of the three scenarios on different mobility data sets. The average delivery latency of DISCUSS in the dynamic scenario was observed to be almost similar to that in the global scenario, for all the mobility data sets, except the Sassy mobility trace. Fig. 10 shows some variation in delay between the global and dynamic cases because of incomplete information. In the HCM, Infocom06, and RWP cases the average delivery latency of the messages in the dynamic scenario is less than that in the static scenario. In these mobility data sets, the number of inter-node contacts is more. So, as the size of the cooperator increased, more messages were delivered and the delivery delay was reduced in the dynamic scenario. For example, using the HCM mobility trace, latency decreased to 136 percent at the end of two days. In the Infocom06 trace, initially the delay was more between 4 to 12 hour, even in the presence of more number of cooperators, as less number of contacts are available. As the number of contacts increased, the delay gradually decreased. In the KAIST, PMTR, and Sassy traces, the average delay in the dynamic scenario is more than that in the static scenario, because less number of contacts are available. So, the message delivery latency is less.

8 Conclusion

In this paper, we proposed a distributed cooperation mechanism, named DISCUSS, for stimulating the non-cooperative nodes to cooperate for forwarding the other nodes' messages. After a generation interval, each node compares its own performance with the performance of the other groups and selects the most successful strategy accordingly. We verified the similarity and effectiveness of DISCUSS in different scenarios. We compared the performance of dynamic DISCUSS with the static DISCUSS, without changing the initial chosen strategies. Extensive simulation results show that the dynamic DISCUSS is better than the static DISCUSS. In the future, this work can be extended by



(a) HCM (b) Infocom06

Fig. 11. Variation in percentage of cooperators under light traffic load.

exploring other possibilities of non-cooperative node strategies. Also, the proposed mechanism can be extended by considering the privacy and security aspects of SD-OMN. We, further, plan in the future to validate the results using a real-life test-bed.

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